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A. C. TRUE, Director
In Cooperation with the Bureau of Plant Industry
W. A. TAYLOR, Chief

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ILLUSTRATED LECTURE ON GREEN MANURING

By

A. J. PIETERS, Agronomist in Charge of Clover Investigations, Bureau of Plant Industry

CONTENTS

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SYLLABUS 34—ILLUSTRATED LECTURE ON GREEN MANURING.[1]

By A. J. Pieters, *Agronomist in Charge of Clover Investigations, Bureau of Plant Industry.*

DEFINITION.

View.

The term "green manuring" signifies the turning under of green plants for the enrichment of the soil. Taken broadly, this would mean the turning under of weeds or of the aftermath of a grass or clover crop, as well as a crop especially grown for turning under, and it is in this sense that Storer uses the term in his Agriculture, Vol. II. He says, for instance, that the turning under of an old hay sod is "green manuring, pure and simple." As commonly understood, however, the term is used in a narrower sense and is taken to apply to the turning under of a green crop especially grown for this purpose, or if not especially grown, at least used in that way rather than put to some other possible use, as when the second crop of clover is turned under instead of being cut for hay or for seed.

HISTORICAL.

Green manure crops were used by the Ancients, the Romans using lupines which were sown in September and turned under in May for the benefit of the following crop. The use of lupines found its way into Germany in the middle of the nineteenth century and has proved an important factor in reclaiming the sandy lands of parts of Prussia.

[1] This syllabus has been prepared by direct cooperation between the Office of Forage Crop Investigations of the Bureau of Plant Industry, as regards subject matter, and J. M. Stedman, Farmers' Institute Specialist of the States Relations Service, as regards pedagogical form. It is designed to aid farmers' institute and other extension lecturers in presenting this subject before popular audiences. The syllabus is illustrated with 50 lantern slides. The numbers in the margins of the pages refer to the lantern slides as listed in the Appendix.

In England both legumes and various crucifers are commonly used, while in India the natives gather green plants of many kinds, sometimes even cutting twigs from the trees and carrying this material to their rice fields. In China green plant
material is composted and turned under. 1

In the United States the use of a special green manure crop is much more general in the South than in the North. In the semiarid regions green manures are not used for the reasons that will be made clear later, but in southern California green manures play an important rôle in the citrus belt.

FUNCTION OF GREEN MANURES.

Green manures are used to maintain or to increase the fertility of the soil. Soil fertility depends in general on three sets of factors—physical, chemical, and biological, although the latter may ultimately be expressed in terms of the chemical factors.

PHYSICAL EFFECT OF GREEN MANURES.

Organic matter increases the moisture-holding capacity of soils. Added to a heavy clay it lightens it and prevents the compacting of the soil; added to a sandy soil it enables it to hold moisture better.

For the best growth of plant roots both air and moisture are needed. When a stiff soil dries and becomes hard the air is
shut out. The roots suffer in consequence, not only from lack 2
of moisture, but from lack of air. In a soil full of organic mat-
ter plant roots grow rapidly and feed widely, but in a soil 3
poor in organic matter root growth is restricted.

Not only do the higher plants themselves grow better in a soil rich in organic matter but the activities of the soil bacteria are largely dependent on the supply of decaying vegetable matter. These bacteria need food and air. The food they find in the vegetable matter, which they break down and make available to the higher plants. The beneficial bacteria use air, and this they find more abundantly in a soil supplied with organic matter than in stiff clays, poor in organic matter. In sandy soils there is air enough, but here the humus helps to hold moisture and so benefits the bacteria as well as the higher plants. The water-holding power of humus is well shown in the dia-
gram on the slide. This shows that pure humus may hold 4
almost double its weight in water, while sand holds but one-quarter of its weight of water. The greater water-holding capacity of the garden soil over the cultivated soil was largely due to an increased percentage of humus in the garden soil.

The very fact, however, that humus holds moisture renders it undesirable for wet lands; on these an increase in the humus may result in putrefaction instead of decay and the subsequent loss of nitrogen and the formation of insoluble organic compounds.

Besides the beneficial effects of humus on the aeration and moisture-holding capacity of soils, it has a good effect on the soil temperature, tending to make it cooler by day and warmer by night and generally keeping the soil temperature more uniform.

CHEMICAL EFFECTS.

Before green plants turned under can be used by the next crop they must decay. Decay is brought about by several of the lower organisms, and the process is somewhat complex. Eventually, however, the inorganic constituents are set free, and it is an important fact that the phosphorus and potassium derived from decaying organic matter are more available for the next crop than when naturally found in the soil and not derived from the decay of organic matter.

The amounts of inorganic materials in plants vary but are in no case very large. The table on the slide, prepared from 5
information in Fertilizers and Crops, by Van Slyke, shows the number of pounds of phosphoric acid and of potash in 1 ton of green plant material.

These amounts of phosphoric acid and of potash would be removed from the soil if the crop were harvested. When the crop is turned under they are not added to the soil because they were in it originally, but they are returned to the soil in a more available form than that in which the same elements are originally found in the soil. On the other hand, when manure or commercial fertilizers are used, the amounts of phosphoric acid and of potash they contain are actually *added* to the soil. With this distinction well in mind, it may be interesting to compare the quantities of phosphoric acid and potash available to a crop of corn, say, when a standard fertilizer is used, with the quantities turned under in various green manures. The quantities of fertilizing elements present in roots and stubble are not taken into account, as these are returned to the soil in any case, whether the parts above ground are made into hay or are used as green manure. For corn on land poor in organic matter Van Slyke suggests a fertilizer which, applied at the rate of 500 pounds per acre, will contain 40 pounds of phosphoric acid and 25 pounds of potash. Taking a yield of 8 tons of green matter per acre as a fair average for a green-manure crop (and this has been frequently exceeded), the amounts of phosphoric acid and potash returned to the soil,

when such crop is turned under, will be as shown in the table 6
on the slide.

It will be evident that, so far as phosphoric acid and potash are concerned, the turning under of a green crop will supply the corn with as much potash, but not with as much phosphoric acid, as would be furnished in 500 pounds of 3:8:5 fertilizer.

But the fact that the inorganic food elements are more available when derived from decaying plant material is not the only result secured by turning under a green crop. The decay of the plants results in the formation of carbonic acid and organic acids which increase the ability of the soil water to dissolve the potash and phosphoric-acid compounds in the soil.

That green manuring is an effective means of increasing the availability of potash in soils was strikingly shown in experiments at the Illinois Experiment Station with red clover grown on soil from which a large part of the potash had been extracted by treatment with strong acid according to the method usually followed in chemical analysis of soils. Pots 3 and 4, in the view herewith, show that after two years of green
manuring red clover was able to secure sufficient potash from 7
such extracted soil to make a better growth than the plants on normal unfertilized soil. As will be seen, no growth was obtained in pot 5, which contained sand, to which had been added all of the necessary fertilizers except potash.

Green manures actually add nothing to the potash and phosphoric acid of the soil as a whole, but, as shown above, they increase the availability of these inorganic constituents. Moreover, many of the leguminous plants used as green manures have deep-feeding roots which bring up fertilizing constituents from the subsoil, with the result that when the plants are turned under the surface soil is enriched to this extent at the expense of the subsoil.

NITROGEN.

The most important single element required by plants is nitrogen; not that this is more necessary to growth than the mineral salts, since all are absolutely essential, but because (1) larger quantities of nitrogen than of the mineral salts are used, (2) the nitrogen in the soil is more subject to loss by leaching than are the mineral salts, and (3) the nitrogen is the most expensive single element of plant food.

Fortunately, an inexhaustible supply of nitrogen exists in the atmosphere. The higher plants, however, can not use

directly the uncombined nitrogen of the air. In three ways the amount of available nitrogen in any particular soil may be increased by the aid of microorganisms which are able, when carbon is supplied, to take the nitrogen from the air or to change organic nitrogen to nitrates. It is probable that at least two of these processes are constantly in operation on all soils whenever conditions of temperature and moisture permit. Though individually insignificant, the enormous numbers of these microorganisms make possible a very considerable deposit of nitrates. The three processes referred to are:

(1) Growth of the nodule bacteria in the roots of various legumes.

(2) Ammonification and nitrification of organic matter turned into the soil, as manure.

(3) Growth of nitrogen-fixing bacteria of the Azotobacter group.

All of these processes are either dependent on, or greatly stimulated by, the turning under of organic matter.

NODULE-FORMING BACTERIA.

That legumes benefit the land was known long before Hel-
riegel and Willfarth demonstrated that this beneficial effect
is due to the nodules on the roots. Since their time much work
has been done, and it is now known that certain microorganisms
enter the roots of legumes, being at first resisted by the plant;
that they take from the host plant the starch compounds they
use, and while living in the roots assimilate the nitrogen of the
air. Just how the legume gets the nitrogen is still a disputed
point, but that it gets it is well established. The nodules are
swellings on the roots of the legumes and are caused by the
irritation which the nodule organism sets up. These nodules 8
consist of thousands of cells, as shown on the slide. Each cell
is packed full of material with a high nitrogen content as well 9
as millions of minute organisms somewhat like those shown at
the right.

When planted on soil rich in nitrates, legumes will grow as
well without nodules as with them, but on poor soils the growth
of the legume is dependent on the presence of nodules. With-
out these the plants show a stunted growth and yellow color, due
to lack of nitrogen. Note on the slide the much smaller growth
of the alfalfa plant to the right than of that to the left. The 10
one had nodules, the other did not have them.

In the next slide note the difference between the sweet clover 11
inoculated, at the left, and that not inoculated, at the right.

The seed was sown at the same time on the same soil, but one lot of seed was inoculated, the other was not. It is well known that the nitrogen found in a crop of clover or other legume did not all come directly from the nitrogen of the air; a part was taken from the available supply in the soil. Just how much comes from the air and how much from the soil can not be stated. The proportions doubtless vary widely. Legumes grown on a poor soil and well inoculated doubtless get a larger proportion of their nitrogen from the air than legumes grown on a rich soil. The Michigan Experiment Station grew soy beans, inoculating the soil on one field and leaving another uninoculated. Samples taken and analyzed showed that about two-thirds of the total nitrogen was taken from the soil and one-third from the air. The Illinois Experiment Station grew alfalfa, both in pots and in field plats, some inoculated, others not. The alfalfa on the inoculated plats contained in the crops for a season 156 pounds more nitrogen per acre than did that from the uninoculated plats.

At the Canada Experimental Farm at Ottawa experiments were conducted with red clover, which was grown on specially prepared plats of sandy soil with a known nitrogen content. All the clover raised was turned back to the soil for nine years. At the end of this time the soil contained 472 pounds of nitrogen more than at the beginning. As a result of a similar experiment carried on by the New Jersey station, the conclusion seems warranted that in this case the legumes took from the air and made available to the grain crops at least 54 pounds of nitrogen per acre per year.

Analyses of crimson clover and of cowpeas and other legumes have been made, showing contents of nitrogen in the above-ground parts averaging in the neighborhood of 200 pounds per acre. Hopkins concludes that on the average about two-thirds of the nitrogen in a clover crop comes from the air. If this is true, a well-grown crop of legumes may be expected to add between 100 and 130 pounds of nitrogen per acre to the soil. This would be equal to 700 or more pounds of nitrate of soda—an extremely heavy application. However, our information at present is too imperfect to permit any positive statements; it is certain that a thrifty crop of legumes does add nitrogen to the soil if it is turned under, but how much nitrogen any crop may add to the soil can not be stated.

In order that leguminous plants may get the atmospheric nitrogen, the nodule organisms must be present in the soil. If these germs are not naturally in the soil, they may be put there by one of several methods. It must be stated here that while

the germs living in the nodule look alike they do not always act alike. Those able to enter the roots of red clover can also enter the roots of alsike, white or crimson clover, but can not live in the roots of alfalfa, soy beans, sweet clover, or any legume not closely related to red clover. Just how closely related plants must be to harbor the same germ can not be stated. The alfalfa germ will also live on sweet clover, though this plant does not belong to the same genus as alfalfa.

These germs can be artificially cultivated, and such pure 12
cultures can be used to inoculate the seed before planting. Soil on which a green leguminous crop has grown, if the roots have been supplied with nodules, may be scattered on the field to be planted with the same crop. Pure culture inoculating material may be had from the United States Department of Agriculture.

NITRIFICATION.

When any organic matter such as crimson clover, the turning under of which is illustrated in the accompanying slide, is turned into the soil certain microorganisms at once attack it and, if oxygen is present, decay sets in. This consists essentially in the breaking down of the complex organic compounds 13
into simpler ones. So far as the organic forms of nitrogen are concerned the change to nitrates requires the cooperation of three distinct organisms, all living together and all commonly working together so harmoniously that one step follows another without interruption. The first set of organisms breaks down the organic nitrogen compounds into ammonia, and under favorable conditions this process may go on so rapidly that ammonia gas passes into the atmosphere and may be detected by the organs of smell. In the decay of green plant material in the soil, however, the ammonia is used by another organism as fast as it is produced or it is absorbed by the soil. The ammonia is used by the nitrite-producing organism to form nitrous acid, and the product of its life activity is a poison to higher plants. There is, however, another germ which uses this product so rapidly that it is next to impossible ever to find any of the poisonous product in the soil. This last germ changes the nitrous acid into nitric acid, and this combining with lime or some other base produces a nitrate; in this form the nitrogen can be utilized by the higher plants.

The accompanying slide shows diagrammatically the pro- 14
cesses of the nitrogen cycle. It should be distinctly understood that each change is due to the activities of different bacteria or microorganisms. The nitrogen contained in the

green crops turned under is thus made available for the next crop. When a crop of rye or of weeds or of any common farm crop except a legume is turned under, however, no *nitrogen* is *added* to the soil. The accompanying slide shows the turning
under of rye as a green-manure crop. All of the nitrogen in 15
the rye came from the soil, and turning it under does not add any nitrogen, though in decaying it may make it possible for other organisms to live and to take nitrogen from the air, thus benefiting the soil indirectly. Only that which was in the soil is returned to it and returned finally in the same form as that in which the first crop took it; there can be no gain in the process, but there *may* be some loss.

When, however, the organic matter is hauled on to the land, as in manure, straw, or rubbish from other fields, the nitrates produced are *added* to the field in question.

NITROGEN-FIXING ORGANISMS.

Besides the nodule germs and the ammonifying and the 16
nitrifying germs there is another class of organisms known as nitrogen-fixing bacteria. These are commonly spoken of under the name Azotobacter, though this form is but one of several that seem to have the power of fixing in the soil the nitrogen of the air without living in the roots of plants. The organisms of the Azotobacter type thrive in the presence of oxygen, but another type of nitrogen-fixing germ known as Clostridium can fix atmospheric nitrogen only in the absence of oxygen. All of these organisms, however, must have a source of carbon, and the cellulose which makes up the cell walls of plants and whatever starch and sugar may be in the plants turned under serve as a source of carbon, so that the growth and activity of these nitrogen-fixing forms is directly dependent upon a liberal supply of organic matter in the soil.

How much nitrogen the organisms of this type fix is not known. At the Rothamsted station in England it was found that land which had received no nitrogenous fertilizer and on which no leguminous crop had grown for 20 years had increased its supply of nitrogen by 25 pounds per year per acre. This is believed to have been added by such nitrogen-fixing forms as Azotobacter.

For the vigorous development of these forms a good supply of calcium carbonate is necessary. When a green-manure crop is turned under with lime the nitrogen-fixing power of the soil is much greater than when the same crop is turned under without lime. It also appears that some of these microorganisms,

though they may be able to fix nitrogen alone, can do better when growing in a mixture with other forms. The reasons for this are not well understood, but it is being constantly better appreciated that the soil is a very complex thing. There are actions and interactions; chemical and physical forces are constantly at work, and changes are going on all the time. So, too, with the biological forces, one form of organism affects another, but though it is not fully known in all cases just how one form affects another it is known that a plentiful supply of organic matter is necessary or at least helpful for the full activity of the forms that are beneficial to crops.

GREEN MANURE v. STABLE MANURE.

A leguminous green-manure crop returns to the soil the phosphoric acid and potash it took from it, and adds some nitrogen and a quantity of organic matter. All these may also be added in stable manure, with the difference that the fertilizing material in the stable manure is really added to the soil. Few data are available to show which form of manuring will add most to the soil. The New Jersey Experiment Station calculated that two crops of green manure would contain as much phosphoric acid and potash, and nearly as much nitrogen and organic matter, as 20 tons of stable manure as used by the sweet-potato growers of New Jersey. 17

The nitrogen in the green-manure crops was more available than that in the stable manure and hence more valuable. The cost of the stable manure given is exclusive of putting it on the land, and from these figures it appears that the 9,000 pounds of organic matter have *cost* $18.40, while the value of the fertilizer ingredients alone in the green-manure crops is in excess of the total cost of producing the green-manure crop *on the land*. The distribution of the organic matter in the green manure would be better than that from the stable manure, and hence the smaller quantity would probably be as valuable as the larger. In the course of these experiments the New Jersey station showed that the leguminous green manure was more efficient than the stable manure in the matter of crop production and in maintaining the nitrogen content of the soil.

EFFECT OF A GREEN-MANURE CROP ON THE YIELD OF A SUBSEQUENT CROP.

The value of any particular soil treatment must be determined by the yields of crops resulting from the treatment. In the South the Alabama Experiment Station has shown that

the turning under of a legume increased the following cotton 18
crop by 63 per cent over that on land continuously in cotton. The yield of corn was increased 81 per cent, and substantial increases were also noted in small grain crops.

Similar results have been recorded by other stations in the 19
South.

Increased yields of potatoes and corn have been recorded by certain eastern stations as a result of plowing under a crop of crimson, alsike, or red clover, the Delaware station, for example, recording better yields of sweet potatoes following crimson clover plowed down than from an application of 160 pounds of nitrate of soda per acre.

At the Central Experimental Farm, Ottawa, Canada, extensive tests with red clover sown with grain and turned under for the next grain crop showed that the yield of the second 20
crop was much larger where the clover had been turned under.

In California a leguminous green-manure crop returned greater yields than a nonleguminous green manure crop, and even when large applications of nitrate of soda were added to the nonlegume crop the resulting yields of corn, potatoes, and 21
beets did not exceed those from the legume plats without extra nitrates.

RESIDUAL VALUE OF A GREEN-MANURE CROP.

It has been observed that when a green-manure crop is turned under the benefit from this may last for two or more years. The Alabama Experiment Station found that two years after a crop of cowpeas or of velvet beans had been turned under the crop of corn was considerably larger than on adjoining land previously cropped to cotton.

The Canada Experimental Farm at Ottawa found that this residual effect of red clover might extend to the third year. In the accompanying view the yields for three years following the turning under of a crop of clover are given in round num- 22
bers. Without exception the yields were better even the third year as a result of turning under this clover crop. Not enough is known about this to generalize safely, but these data are given to show that under certain conditions at least the benefit from turning under a green-manure crop is not confined to the crop immediately following.

In the Western and Northwestern States a green-manure crop has not given the positive results that have been secured in the South and East. Whether this is due to lack of moisture or to other causes can not at present be determined. The North Dakota and the Minnesota stations claim small gains in wheat yields as a result of using a catch crop of clover.

DOES IT PAY TO TURN UNDER A GREEN-MANURE CROP?

This is a question of some complexity, and can be answered only in general terms. Where a leguminous crop can be fed to stock and the manure can be properly handled and returned to the land, the net returns to the farmer will usually be greater where the crop is fed than where it is turned under. Experimental data are wanting. The Georgia Experiment Station showed that the total value of the produce from a piece of land for two years was greater where cowpea vines were made into hay and the stubble alone turned under than where the whole crop was turned under. To be conclusive, however, such an experiment would have to run long enough to affect the supply of organic matter in the soil. This would certainly be depleted in case the cowpea hay were sold off the place, and in time such a field would probably return decreased yields. Among the considerations that must determine whether a given green crop shall be turned under or not the following may be mentioned:

(1) The richness and physical condition of the soil. On a rich soil in good tilth the turning under of a crop would be wasteful, while on a poor or stiff soil it may be good practice.

(2) The character of the crop and the time when it is ready to cut. Crimson clover, for instance, often comes to the hay stage at a time when the weather conditions make it hard to cure. It is especially valuable for turning under, to be followed by a summer crop, which gets the benefit of the green manure. It may be wisest, therefore, to turn it under rather than to take a chance on making a lot of poor hay.

(3) The lack of stock to which to feed the hay on the place may make it better practice to turn the crop under than to sell the hay.

(4) The price of hay at times may not warrant the expense of making a crop into hay in view of the value of the fertilizer constituents in the plants. In tests at the Delaware Experiment Station it was shown that the value of the phosphoric
acid, potash, and nitrogen in a ton of clover hay was between 23
$9 and $10. This was exclusive of the value of the organic matter, for which, as stated on page 9, the New Jersey Experiment Station showed that sweet potato growers paid $4 per ton in stable manure. If we add $4 per ton to the figures shown here, we get values all the way from $10 to $14 per ton, which the crop was worth to the farmer to turn under. To this must be added the cost of making the hay

before he could fix a price that would yield a profit, and unless he could feed the hay or sell at a profit he might better improve his land by turning the crop under.

This aspect of the problem is one of farm management, and must be solved by each farmer in accordance with his conditions, remembering that if a leguminous crop can be fed on the place and the manure, properly saved and returned, there will usually be more profit than in turning the crop under, while if the hay is to be sold a good price must be obtained to pay for the fertility removed from the soil.

WHEN TO TURN UNDER A GREEN-MANURE CROP.

While no definite dates can be given for the turning under of
a green-manure crop, certain general considerations will gov-
ern. To be useful to the next crop a green crop must decay,
and for this moisture is essential. In the process of decay also
certain substances are produced, and it has been found that
during the early stages of decay there may be injurious effects
on seed planted too soon after the green crop is turned under.
The slide shows the effect on the germination of cotton when 24
the seed was planted as soon as the green manure was mixed
with the soil. Pots A and B had no green manure; C and D
had green manure at the rate of about 5,000 pounds per acre;
E and F 10.000 pounds; and G and H 20,000 and I and J
20,000 pounds green manure per acre. The seeds were planted
at once. Note that where only 5,000 pounds per acre was
turned under the germination was reduced, and where 10,000
pounds was used, which is only a small green-manure crop,
the stand was nearly a failure. In the second row of pots the
treatments were the same as above, but the seed was planted
two weeks after the green manure was turned under.

A green-manure crop, therefore, should be turned under
some time, at least two weeks, before the next crop is planted.
This depends, of course, somewhat on the quantity of green
stuff plowed down and on the crop to follow; cotton seedlings,
for example, are more sensitive to the injurious substances
than is corn. The turning under of this green matter also in-
terrupts the capillarity of the soil, especially if the furrow slice
is laid flat. In plowing down, therefore, the furrow slice
should be laid slanting; an angle of 30° to 40° with the hori-
zontal is recommended. The soil should also be thoroughly 25
rolled so as to compact it about the mass of plant matter as
much as possible. This will hasten decay and prevent drying
out of the soil. This compacting may be done with any one of 26

several kinds of roller from the common smooth roller to various types of corrugated or special rollers, as shown in the
slides. 27

While the time when a given crop must be plowed down may depend largely on other considerations than the maturity of the green-manure crop, the fact that such a crop may increase greatly in value during the later stages of growth should not be overlooked. The Delaware Experiment Station showed that the gain in nitrogen made by a crop of crimson clover during the month before full bloom depended on the thickness of the stand and the richness of the soil in nitrates. The plants of a thin stand on poor soil acquired a larger part of their nitrogen during this month and should, therefore, be allowed to stand as long as possible, while those of a thick stand, especially on soil that had frequently grown clover and was consequently well supplied with nitrates, increased little in nitrogen during this time and might as well have been turned under early.

MOISTURE AND A GREEN-MANURE CROP.

A growing crop removes moisture from the soil, and this removal of moisture may become the critical factor. In the South it has been found that cowpeas grown with corn often reduce the yield of corn for that year. This is believed to be because the moisture is not sufficient for both the corn and the cowpeas. In the peach section of Michigan a winter cover and green-manure crop is wanted that will make a good growth in late August so as to draw the moisture away from the trees and force the ripening of the wood. In Nebraska the orchard cover crops recommended are such as are killed by the first frost; others, as rye, taking too much moisture from the ground in late winter and early spring.

In the South, East, and North, green-manure crops are commonly turned under at a time when the supply of moisture is ample for decay, but if a dry spell should chance to follow the turning under of a heavy crop of green matter the soil should be well rolled and compacted to prevent drying out. In the semiarid parts of the West and Northwest moisture is the critical factor in crop production, and any practice that reduces the moisture supply of the main crop is to be avoided. The Office of Dry-land Investigations of the United States Department of Agriculture has found that green-manure crops that make their growth so as to be turned under late are usually injurious. They not only take up the soil moisture while growing but absorb large amounts when turned under, and leave the

soil more exposed to drying than before. If, however, a crop, as rye, can be turned under early, before the close of the rains, some benefit may accrue since the green manure will hold the extra moisture and help prevent drying of the soil.

GREEN-MANURE CROPS.

Green-manure crops may be either summer or winter crops or catch crops that are grown in late summer. In the South winter crops are especially valuable, as they first take up the nitrogen that has been produced during the late summer, next cover the ground in winter and prevent leaching and washing, and lastly occupy the ground at a time when regular money crops can not be grown. In the North rye, clover, and hairy vetch serve this purpose, but naturally as much growth can not be made as is secured in the South. A catch crop is one that occupies the ground between main crops. Red clover may be sown with wheat to be turned under for the next wheat crop; in some sections cowpeas or soy beans may make some growth if planted immediately after grain harvest, to be turned under for the next crop.

Nearly all crops used for green manuring belong to one or the other of three great classes of plants—legumes, crucifers, or grasses.

REGIONAL DISTRIBUTION OF GREEN-MANURE CROPS.

In a general way green-manure crops may be considered with
reference to their use in the South, the North, on the middle 28
Atlantic seaboard, and in the irrigated orchards of California.

In the South—that is, the cotton belt—both winter and summer green manures may be used. For the former bur clover, crimson clover, and vetch are well suited, while for the latter cowpeas and velvet beans are almost universally used. The benefits from green manuring have been most striking in the South, where rundown lands have been restored to fertility largely by this means. The accompanying slide gives a rough picture of these sections. It must not be inferred that the crops mentioned are confined to and the only ones used in the sections named. This is not so. The slide is simply meant to show the sections where the crops mentioned are the mainstay in the work of soil improvement by green manuring. In the area left white, manuring is hardly practiced except in such an incidental way as the plowing up of old alfalfa fields, etc.

On the Middle Atlantic seaboard crimson clover is the chief green-manure crop, while in the North red clover, although not often sown especially for green manure, is used in rota-

tion, and the fall and spring growth turned under adds a considerable amount of green matter to the soil. Hairy vetch and rye are also extensively used for green manure.

In California green manuring plays a considerable rôle only
in the irrigated-orchard sections. Here the seed is planted in 29
the fall and the crop makes its growth during the winter. During the summer the soil is kept cultivated after the green-manure crop is turned under. The crops that have proved best in southern California are all legumes, vetches and field peas being most commonly used until recent years, when the use of the annual melilot has become more frequent.

LEGUMES.

Legumious plants are the ones most used for green manuring in this country and have the advantage over all other classes of plants of being able to use the nitrogen in the air.

RED CLOVER.

Red clover is a biennial and is the standard legume in farm
rotations in the Northern States. It is commonly seeded with 30
grain, cut for hay once, and for seed if conditions are right, and the aftermath pastured or turned under for the following crop. Probably most of the red clover seeded is put in with timothy. Mammoth clover, a large-growing form of red clover, is much used for soil improvement, as it makes a larger mass of growth than the medium red. The beneficial effect of the crop on the yield of following crops has already been referred to. Red clover is not infrequently seeded on wheat to be turned under as a green manure for the next crop either that fall or the following spring. At the Central Experimental Farm of Canada it was shown that winterkilling of red clover did not destroy its fertilizing value. With the exception of its use as a catch crop the entire growth of red clover is probably never turned under for green manure—it is too valuable for forage or for seed. The roots and stubble, however, contain a much larger percentage of fertility than is the case with
most legumes. The roots of red clover extend to a depth of 31
from 4 to 6 feet, but much the largest portion is in the upper foot of soil. The proportion of root to top has been variously estimated. The Minnesota and Delaware experiment stations found nearly one-half as many pounds of root as of top; the Wisconsin station one-quarter as much; the Canada Experimental Farm more than two-thirds as much; while in year-old clover in Michigan the weight of roots nearly equaled that of tops.

The percentage of the total fertilizer ingredients in the crop that is found in stubble and roots is also larger in red clover than in any other legume save alfalfa, though figures on sweet clover are not available. The Delaware Experiment Sta- 32
tion found that 30 per cent of the money value of the fertilizers in the crop was in the root. Red clover, therefore, is better suited than most legumes to a place in the rotation which requires the removal of the parts above ground and the use of the stubble and roots for keeping up the fertility of the soil. However, it must not be thought that such a system can be continued indefinitely. It has been found that turning under roots and stubble only once in three years is not often enough to maintain the fertility of the soil. The supply of organic matter is not kept up.

CRIMSON CLOVER.

Crimson clover is a winter annual and is an important crop 33
along the Atlantic coast from New Jersey south, and in many parts of the Cotton Belt. There are isolated places outside of these limits where it is used, as, for example, at Concord, Mass., and in Wayne County, N. Y., but such use is limited to special soils and conditions. On the Atlantic seaboard and in portions of the South it is the great winter cover and green-manure crop. While the root system is extensive it does not compare favorably in this respect with red clover, the Delaware Experiment Station finding but 10 per cent of the air-dry substance in the root as against 30 per cent for red clover. However, the nitrogen content in the entire plant is greater in crimson clover than in red, Henry, in Feeds and Feeding, giving this as 1 to 2 per cent higher in the former. From Delaware to the Gulf of Mexico it is frequently seeded at the last working of the corn or cotton and turned under for the next crop. In the South it is necessary to turn it under 34
before it has attained full development when it is to be followed by cotton, but when corn is to be planted the clover may be allowed to come into bloom or a seed crop may even be taken and the straw be turned under in time to plant late corn. In Delaware, where crimson clover is very largely used as a winter cover crop, it is thought that it should be plowed down at the first appearance of the blossoms. 35

SWEET CLOVER.

This crop is a biennial and has but recently come into prominence as a forage crop and soil builder. In appearance the plants, when about half grown, resemble alfalfa, though the leaves are larger and the plant has a bitter taste. When 36

allowed to mature naturally sweet clover makes a straggling,
bushy plant, 5 or more feet high with small white flowers on
slender racemes at the ends of the twigs. An important char-
acteristic of this plant is the very large taproot, which is pow-
erful enough to penetrate stiff clay soils and in which a great 37
quantity of reserve food is stored up during the first season's
growth. Yields as high as 30 tons of green fodder per acre
have been recorded, but there is yet no adequate record of the
relation between roots and tops. The composition of sweet
clover is nearly the same as alfalfa, showing that turning un-
der a good stand of this crop would furnish a large amount
of fertility for the succeeding crop. Sweet clover is grown as
a soil-improving crop in parts of Mississippi and Alabama, as
was shown on the slide. In this section it is perhaps the most
important soil improver. It is also used for this purpose in
parts of Kentucky, Illinois, Iowa, and eastern Kansas.

Sweet clover will thrive on almost any soil provided it has
plenty of lime. In this respect it has a wider range of useful-
ness than either red clover or alfalfa, doing well on soils too
poor to produce a crop of either of these two plants. It
thrives in all parts of the United States. North Dakota is not 38
too cold, nor is Alabama too hot, and it will get along with less
water and more salt in the soil than any other valuable legume
we know.

The seed is sown either hulled or unhulled. If the latter is used it should be sown in fall or winter so that the changes in temperature may make the hard seed coat permeable to water. Hulled seed is not so hard and should not be sown before early spring. The seed bed for sweet clover needs to be very firm, and good stands have been obtained by seeding on land so hard that the drill would barely leave a mark. On land that has never grown sweet clover the seed should be inoculated. When grown in the South soil on which bur clover has grown may be used for inoculation, as the same organism inhabits the nodules on the roots of sweet clover, alfalfa, and bur clover.

SOY BEANS AND COWPEAS.

These are both annual, summer crops, and to a large extent 39
occupy the same place in agriculture. The cowpea is used as
a green-manure crop much more than the soy bean, but the use
of the latter is increasing. Soy beans can be grown farther
north than cowpeas, but they do not keep down weeds as well
as cowpeas. Both are nitrogen gatherers, but while the germ 40
for the cowpea nodules seems to be widely distributed that for

the soy bean is not found naturally in our soils; the seed must
be inoculated when first planted. When selecting a variety 41
for green manuring care must be taken to get one making a
large growth. Soy-bean varieties are extremely different, some 42
being very early with relatively many pods and small leafage, others having a great growth but late and maturing relatively a small number of pods. In the South it is a common practice to plant cowpeas in the corn at the last cultivation. This has been found sometimes to decrease the yield of corn since the cowpeas draw heavily on the moisture. Many experiments in the South have given evidence of the value of cowpeas and soy beans as green-manure crops. In nearly all cases corn and cotton yielded more after one of these crops had been turned under than before. The results with soy beans have been more conflicting than those with cowpeas, but this is probably because of the lack of inoculation for soy beans.

For use as a green-manure crop only the cowpea is perhaps 43
the more valuable, except in the North, where light summer frosts are liable to occur. The soy bean will withstand such a frost, while the cowpea will not. Both are subject to the same diseases, of which a root nematode and Fusarium wilt are the only serious ones known. The yields of green matter for
turning under are nearly the same, making due allowance, of 44
course, for the choice of varieties and soils.

VELVET BEAN.

This is a coarse leguminous vine adapted only to the South. Comparative tests of the effect of turning under velvet beans and cowpeas made by the Alabama Experiment Station resulted rather in favor of the former, but the trials recorded are not numerous enough to warrant a positive statement. As a plant for growing on newly cleared land it is excellent, as it makes a heavy growth and smothers out all other plants. The growth is indeed sometimes so heavy that the Florida Experiment Station considered it inadvisable to turn under the entire crop green, but stated that it was better to allow the vines and leaves to decay on the surface to be turned under the following spring. The amount of nitrogen in root, stubble, and vines was found by the Alabama Experiment Station to be: Roots and stubble, total weight, 1,258 pounds; nitrogen, 12.5 pounds; hay yield, 8,240 pounds; nitrogen, 188.7 pounds; showing that only a small part of the nitrogen is contained in the roots.

BUR CLOVER.

This is without doubt one of the most valuable soil-improving crops for the Cotton Belt and the Pacific coast. It is a winter annual, but will not endure severe cold. In the cotton States its value lies partly in the fact that it can be handled with a minimum of expense, reseeding itself readily, and covering the ground during winter, thus not only enriching the soil at a time when other crops can not be grown, but preventing washing and leaching. When used as a green-manure crop for the benefit of cotton or corn, rows of bur clover may be left standing at suitable intervals when plowing for the summer crop. The burs ripening on the plants thus left will reseed the field for the next winter's stand of bur clover.

There are two species in cultivation, the Southern, or spotted, and the California. Of these the former seems best suited to the Cotton Belt, as it is a stronger grower and resists cold better. The seed of the southern bur clover is commonly sold in the hull, and since particles of dirt commonly adhere to this, there is no need to inoculate. The California seed is hulled and does not carry inoculating germs.

VETCHES.

Two species are more or less used for green manuring—the common and the hairy vetch. The common vetch is a standard green-manure crop in the citrus groves of California,
where it is found to produce a larger amount of organic mat- 45
ter than most other crops and to withstand the trampling at orange-picking time better than Canada field peas. Common vetch may be planted as a winter crop in the South and on the Pacific coast and as a summer crop in the Northern States.

Hairy vetch is hardier than common vetch, and is adapted 46
to a wide range of soils and climates. It is markedly resistant to both drought and alkali. It has been found useful as a green-manure crop for the tobacco fields of Connecticut and is highly thought of in the peach section of Michigan. It makes little growth during the cold weather, when planted in the fall, but grows rapidly as soon as spring opens. In the South it must be sown in the fall as it does not endure hot weather.

CANADA FIELD PEAS.

The field pea is adapted only to cool weather conditions. 47
It may be grown in the South as a winter crop and in the North as a spring-sown crop. Its use as a green manure is

practically confined to the orange section of California and to portions of the Northwest and Canada, where it is sometimes used in this way. It makes a succulent growth which readily decays, but is, in other respects, not equal to vetch and the cost of seeding is materially higher. Where clovers or vetches can be used Canada field peas will scarcely be needed for green-manure purposes.

LUPINES.

Lupines are not much used in this country but form one of the standard green-manure crops for the sandy lands of Germany. It is said that a crop of lupines will add more nitrogen to the soil than any other leguminous crop. In the northern half of the southern peninsula of Michigan are sandy lands on some of which very satisfactory results have been secured by the use of lupines as green manures. One person has stated that lupines were the only legumes that would grow at first on the sandy soil of his farm, and that by turning under two crops of lupines he was able to start other crops and established a profitable rotation. Three species, all annuals, are used; they are known from the color of their flowers, white, blue, and yellow.

HORSE BEAN.

This upright-growing species is widely used in California 48
for soil improvement. In some sections it has been highly recommended as producing an enormous quantity of succulent green matter. It is not, however, generally considered equal to common vetch for this purpose.

CRUCIFERS.

Cruciferous plants are seldom grown in the United States 49
for green manure, though rape is not uncommonly used for hog and sheep pasture. In England, however, both rape and white mustard are frequently used for turning under and under certain circumstances have given better results than a leguminous crop. Crucifers are sometimes called potash crops from their apparent ability to get what potash there is even in poor soils. The Delaware Experiment Station found that the percentage of potash in rape was greater than that in any legume and that the total quantity of potash in a green-manure crop of rape was nearly twice as great as that in any legume tried. This potash is, of course, not added to the

soil but it is supplied to the next crop in more available form. At the Woburn Experimental Farm in England trials were made of rape and white mustard as green-manuring crops in comparison with vetch. In every trial through a number of years the results with mustard, and usually with rape, were much better than those with vetch, and this, too, in spite of the fact that the vetch crop contained the largest amount of organic matter and of nitrogen. At the Rothamsted Experimental Station these results were reversed, but it is evident that under certain conditions the cruciferous crops may give better results than the legumes.

GRASSES.

If we disregard the turning under of sod, the only crops of this kind that are used as green manure are rye and millet. Of course, any young grain or grass crop could be turned under if circumstances warranted, but, as a matter of fact, rye is about the only grain crop that is used in this way.

Rye is perhaps more commonly used as a winter cover and green-manure crop than any other. It is adapted to fall sowing over a wide extent of territory, is extremely hardy, and will make a heavy growth early enough in spring to be turned under for any spring crop. Rye will not add nitrogen to the soil except as the decaying organic matter may furnish carbon as food for the organisms which fix atmospheric nitrogen. It will, however, furnish large quantities of organic matter and will prevent the loss of fertility during winter. In a six-year test on the availability of different forms of phosphorus the Maryland Experiment Station secured better results from plats on which rye had been used as green manure than on those on which crimson clover had been used. The prevailing experience has been, however, that where a legume can be grown the results are better than those secured from turning under rye.

Millet is used only as a summer catch crop and is rarely turned under. So far as recorded evidence goes, it is not desirable as a green-manure crop.

MISCELLANEOUS.

Among crops belonging to other families than those mentioned and which are sometimes used for green manure are buckwheat in the North and Mexican clover in the South.

BUCKWHEAT.

Buckwheat is often grown on poor soil in the North and 50
turned under. It will make some growth on very poor soils, on which clovers would not thrive at all. According to analyses in Henry's Feeds and Feeding, buckwheat ranks high in the amounts of fertilizer constituents per 1,000 pounds of green matter, outranking in this respect even alfalfa and clover; but, of course, all the nitrogen in the buckwheat was taken from the stores in the soil, and by turning the crop under the soil becomes richer only in organic matter and in the greater availability of the mineral fertilizers.

MEXICAN CLOVER.

This plant is not a clover and does not belong to the legume family but to the Madder family, to which coffee belongs. It has been introduced into the Gulf coast section from Central America and grows spontaneously as a weed. On sandy land it is used as a green manure and serves the purpose of supplying organic matter without, however, making the soil richer in nitrogen.

APPENDIX.

LANTERN SLIDES.

No. of view.

1. Chinese farmers making compost by digging under cut greens and grasses and wetting the whole thoroughly.
2. Vertical section of soil on plat growing corn continuously.
3. Vertical section of soil near corn plant growing on newly broken alfalfa sod, showing the fine growth of corn roots in such soil.
4. Diagram showing the relative water-holding powers of soils.
5. Table showing the number of pounds of potash and phosphoric acid in 1 ton of green matter.
6. Table showing the amounts of phosphoric acid and potash in 8 tons of green manure, as compared with 500 pounds of a standard corn fertilizer.
7. Showing plants grown in soil from which potash had been extracted.
   Illinois Experiment Station.
8. Young red clover plant showing nodules upon the roots.
9. Cross section of nodule of lupine and bacteria from alfalfa nodule.
10. Alfalfa plants showing difference in growth, the one at the left having been inoculated with nodule-forming bacteria, the one at the right not inoculated.
11. Sweet clover, showing difference between inoculated and uninoculated plants.
    Seed was sown at the same time and on the same kind of soil, but the plants at the left were inoculated; those at the right not inoculated.
12. Artificial inoculation of alfalfa seed.
13. Plowing under crimson clover and grain stubble.
14. Diagram showing the nitrogen cycle, from the air, through a leguminous plant, back to the air.
15. Plowing under rye for green manure.
16. Some nodule organisms highly magnified.
17. Table showing the relative value of 20 tons of horse manure as compared with two crops of green manure.
18. Table showing the yield of seed cotton, corn, and sorghum in continuous culture and after legumes.
19. Table showing the yield of cotton in continuous culture or after turning under a legume crop.
20. Table showing yields of oats, corn, and potatoes after grain with clover and after grain without clover.
21. Table showing yields of corn, potatoes, and beets after legumes and after barley with and without nitrate of soda.
22. Table showing yields of crops for three years after grain with clover and after grain without clover.
23. Table showing the amounts of nitrogen, phosphoric acid, and potash in a ton of various kinds of legume hay.
24. Showing the effect on cotton seedlings of green manure turned under just before the seed was planted.